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Miniaturized Meander-Line Dipole Antenna For Short-Range Wireless Communication Networks

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***Abstract*—This paper presents the design and performance analysis of a planar, miniaturized meander-line dipole antenna designed for short-range wireless communication links. The proposed compact antenna has a size of $0.08\lambda_o \times 0.03\lambda_o$ (at f_o = 288 MHz) and designed on a sapphire substrate with optimized dimensions of $80.75 \times 31.3 \times 1.5$ mm^3. This electrically small antenna design is comprised of symmetric C-shaped resonators with meandered lines and gaps to perform frequency tuning. Simulated results show that the antenna can be effectively tuned to 288 MHz, 298 MHz and 310 MHz by applying structural reconfigurations. The radiation pattern in all the suggested frequency bands is perfectly omni-directional. The proposed antenna due to highly compact size is a potential candidate for the short-range wireless networks.**

***Index Terms*—antennas, meandered-line, miniaturized, resonators, wireless.**

I. Introduction

Wireless technology has been anticipated as an essential feature of the advanced radiofrequency (RF) devices and systems; and an antenna being a core element requires an efficient design in this regard. The design constraints become more challenging when the antenna needs to be installed in compact footprints along with the other RF components. For microwave devices lower bands of ultra-high frequency (UHF) below 1 GHz are usually used to avoid fabrication complexities. Numerous antenna topologies designed at these frequencies, such as dipole, Vivaldi, horn, log-periodic antennas, etc. cannot be used in many places due to their large and bulky structures which cannot fit within the limited space [1]. Electrically small antennas are projected as the solution, however, accomplishing the desired performance is still difficult due to classical tradeoff among the radiation efficiency, antenna size and bandwidth [2].

Sapphire crystals exhibit excellent material properties for suitable integration of RF components on a single substrate. Silicon-on-sapphire is one of the available technologies to fabricate integrated circuits (ICs). Integrating an antenna on the same substrate along with other RF components offer many advantages such as, miniaturization, cost effectiveness, low power, and high integration of the wireless modules [3]. For instance, an infrared transparent millimeter wave antenna on a sapphire substrate was presented in [4]. Another work on a sapphire-based antenna was reported in [5], where a stacked rectangular dielectric resonator aperture coupled antenna was designed for the C-band applications. In [6], an on-chip miniaturized antenna is proposed on a sapphire substrate for implantable wireless medical systems. The analysis has shown that an on-chip antenna with a silicon substrate has low gain, which is increased by using sapphire substrate instead of silicon for on-chip antennas.

This paper presents a miniaturized tunable antenna at low UHF frequency bands and provides an ease of installation due to its planar structure and compact size. The proposed antenna offers great suitability with numerous applications due to excellent temperature handling capability and optical transparency of the sapphire substrate. In addition, frequency tuning of this antenna does not require any switching devices or ICs which typically need complex biasing circuits and limitations at high-temperature operations.

II. Antenna Design Methodology

This section presents the geometry of the proposed miniaturized antenna capable of frequency tuning at three distinct frequency bands, i.e. 288 MHz, 298 MHz and 310 MHz. It is important to note that the selection of the resonant frequencies of the proposed antenna is application-specific and based on the microwave devices anticipated to be deployed with the designed antenna in future. The antenna with a highly compact dimensions of $0.08\lambda_o \times 0.03\lambda_o$ (where λ_o is the wavelength at resonant frequency, f_o = 288 MHz) is designed on a sapphire substrate (dielectric constant, ε_r = 9.4, loss tangent, $\tan\delta$ = 0.0002, thickness, h = 1.5 mm). For metallization, gold, silver, or copper pastes can be used as several variants of these pastes are commercially available [7, 8]. Frequency tuning can be done by reconfiguring the antenna geometry using aluminum (Al) wire bonding connections. Based on these selections, a miniaturized antenna is designed to achieve desired performance over a short-range communication link. This is highly instrumental where network components are closely spaced, and a single frequency tunable antenna can be used to communicate with devices operating at multiple bands.

The antenna is designed on a sapphire substrate of $80.75 \times 31.3 \times 1.5$ mm^3. CST Studio Suite Software was used for the antenna design, modeling, parametric analysis, and performance evaluation. The antenna design is comprised of a dipole-like geometry augmented with symmetric C-shaped resonators with additional meandered lines positioned inside the C-shaped resonators to increase the radiating length. The upper/lower outer folded strip lines are also aligned with the C-shaped radiators as shown in Fig. 1. The frequency tuning of the proposed antenna is performed by connecting and disconnecting the gaps introduced in the meandered-line structure. For instance, the antenna radiates at a resonant frequency of 310 MHz when the meander-line radiators terminate at L_3 as S_1 and S_2 gaps are open circuit (OC) in this case. While the antenna tunes to 298 MHz when the radiating lines are extended to a length L_2 by connecting all the S_1 gaps with Al-wire bonding. In addition, when the length L_1 is also added in the radiating length by connecting all S_1 and S_2 gaps, the antenna radiates at 288 MHz.

All the dimensions of the antenna are parametrically optimized in the simulation software to achieve the desired functionality. The optimized dimensions of the antenna are tabulated in Table I. The metallic ground plane of size 80.75 × 28.30 mm^2 at the antenna's back fits within the substrate dimensions and avoids integration of huge metallic ground plane as suggested in [9]. Moreover, the proposed structure suggests a use of metallic wire-bond contacts by using Al-wires for frequency tuning, thus avoids use of switching devices/ICs [9] and complex biasing circuitries involved. The proposed antenna can be tuned to one of the proposed bands at one time which is sufficient for many applications. However, this constraint can be addressed in future work.

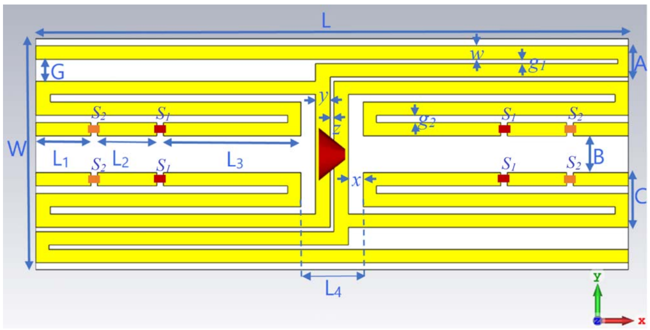

Fig. 1. Simulated model of the proposed miniaturized meandered-line frequency tunable antenna.

TABLE I. OPTIMIZED DIMENSIONS OF THE DESIGNED MINIATURIZED MEANDERED-LINE FREQUENCY TUNABLE ANTENNA

Parameters	***Dimensions (mm)***	***Parameters***	***Dimensions (mm)***
L	80.75	L_1	7.5
W	31.30	L_2	8.1
A($2w+g_1$)	4.2	L_3	18.73
B	5	L_4 ($2x+2y+z$)	8.5
C($3w+2g_2$)	7.4	x	2.0
w	1.8	y	2.0
g_1	0.6	z	0.5
g_2	1.0	Ground plane	80.75×28.30

III. PERFORMANCE ANALYSIS OF THE ANTENNA

The performance of the miniaturized antenna is analyzed by deploying the computational parametric analysis in the CST software. Open/short-circuited (OC/SC) metal contacts were made in the software to reconfigure the radiating length of the meandered lines for frequency tuning.

Fig. 2 shows the simulated reflection coefficient (S_{11}) plots at three distinct bands of 288 MHz, 298 MHz and 310 MHz. The S_{11} magnitude is below -6 dB in all the three bands of interests which is essential for most of the wireless applications. The 2-dimensional (2D) radiation patterns at the E-plane (φ = 90°) and H-plane (φ = 0°) at all the tuned frequency bands of the presented antenna are provided in Fig. 3. The plots show a perfect omni-directional pattern with reasonable directivity. For a comprehensive insight, 3D radiation characteristics of the designed antenna at the frequencies of interest are shown in Fig. 4.

Based on the computational analysis, it has been established that the designed miniaturized antenna due to its small footprint can be a potential candidate for short-distance communication links established among several components on a single substrate. Fabrication of the antenna prototype and experimental characterization will be conducted in the future. For fabrication, screen-printing on the commercially available sapphire substrate is recommended among the several available choices due to its cost-effectiveness and reliability along with decent fabrication accuracy and less complexity. Any suitable commercially available gold, silver or copper pastes can be used in the screen-printing process. In addition, conductive silver spray paints can be deployed for antenna patterning by using an opaque mask on a sapphire substrate [10, 11]. Moreover, another prospective choice is using transparent conductive coatings of indium tin oxide (ITO) and indium zinc tin oxide (IZTO) to make the antenna optically transparent that will extend its application areas to automobiles, energy harvesting and buildings [12].

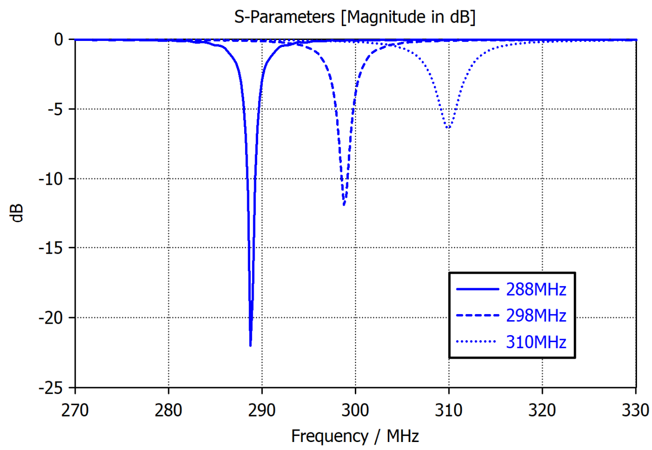

Fig. 2. Reflection coefficient (S_{11}) plots of the proposed miniaturized meandered-line frequency tunable antenna.

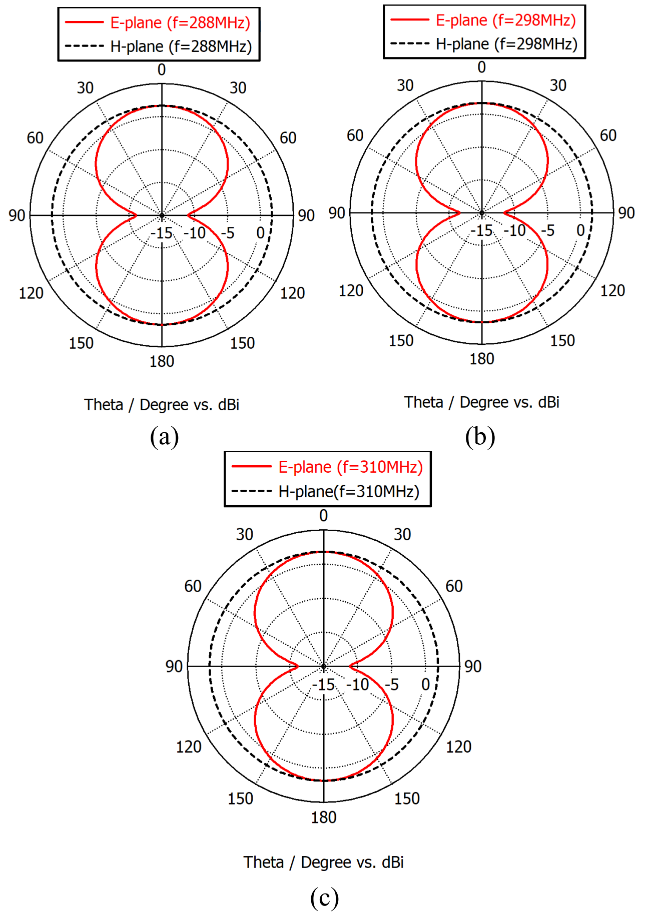

Fig. 3. 2D radiation patterns of the proposed miniaturized meandered-line frequency tunable antenna at: (a) 288 MHz, (b) 298 MHz, (c) 310 MHz.

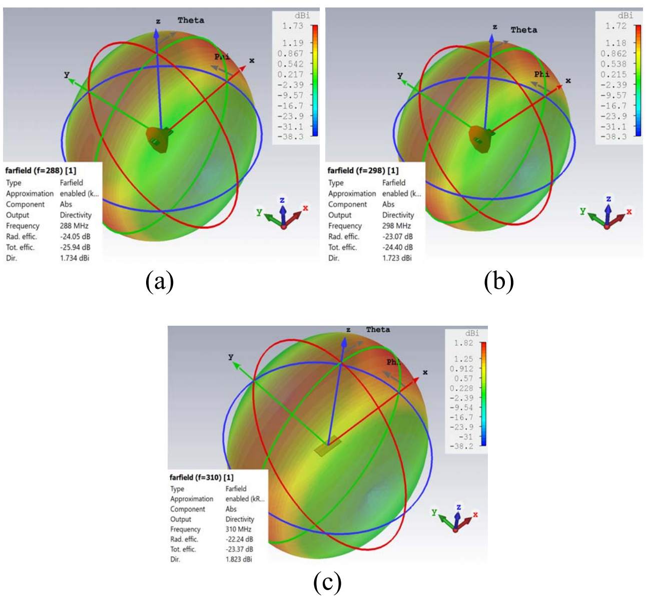

Fig. 4. 3D radiation patterns of the proposed miniaturized meandered-line frequency tunable antenna at: (a) 288 MHz, (b) 298 MHz, (c) 310 MHz.

IV. Conclusion

This paper has presented a planar, miniaturized and frequency-tunable antenna for wireless networks at UHF bands. The antenna was designed on a sapphire substrate of 80.75 × 31.3 × 1.5 mm^3 with a metal-based dipole-like geometry comprising of symmetric C-shaped resonators with meandered lines on the top and a metalized ground at the substrate's back. Meander-lines were designed with gaps to reconfigure the radiating length for frequency tuning which resulted in three distinct frequency bands of 288 MHz, 298 MHz and 310 MHz with a perfect omni-directional radiation pattern in all the bands. Conjunction of commercially available sapphire substrate and metallic paste used in this design as well as achieved small footprint, frequency tunability, planar structure, and optical transparency make the proposed compact antenna a feasible solution for several domestic and industrial applications.

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